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SMOOTHER SAILING

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WORLDVIEW

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3-D EM addresses exploration challenges

Technique helps reduce risk in GoM projects.

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Over the last 10 years, electromagnetic (EM) techniques have become increasingly established as a drilling risk reduction tool in many basins around the world. In 2006 and 2007, a couple of major oil companies acquired EM programs in the Gulf of Mexico (GoM), but in general the GoM has been slow to adopt EM methods — until now.

The reasons for slow adoption in the GoM are rooted in the geology and maturity of the area. Firstly, there is the matter of salt. Salt is highly resistive, and EM energy dissipates rapidly when it encounters salt. This makes subsalt imaging with EM extremely difficult, perhaps impossible. The post-salt regions of the GoM can be considered a very mature basin. With extensive 3-D seismic availability and an active community of independent operators chasing every scrap that the majors have left behind, most of the remaining opportunities are relatively small. EM methods have low resolution in comparison to seismic, and conventional EM wisdom holds that detection of small reservoirs close to large salt bodies is impractical.

In 2008, EMGS worked with Focus Exploration to challenge this accepted wisdom with an aggressive program of eight 3-D EM projects in the GoM.

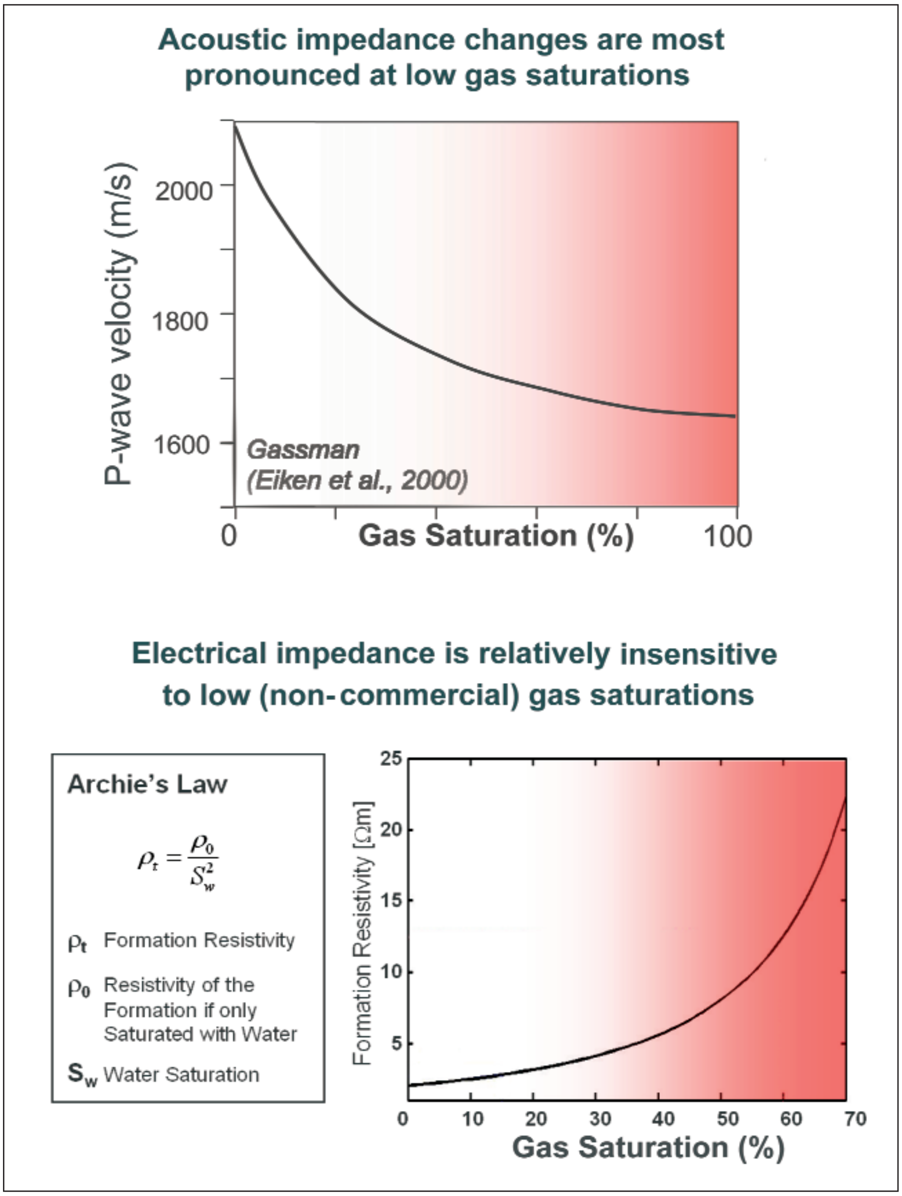

Figure 1. Whereas acoustic impedance is sensitive to low saturation, electrical resistivity is most sensitive to higher saturations. (Images courtesy of EMGS)

The 3-D EM Method

It has been known for more than 80 years that hydrocarbon-saturated sands exhibit higher electrical resistivity than brine-saturated sands. In 2000, researchers at Statoil successfully tested the theory that subsurface resistivity could be measured from the seabed using sensitive seabed data loggers to record the electric and magnetic fields generated by a powerful dipole source towed over a buried resistor such as a reservoir. Multicomponent data loggers are deployed in a grid typically spaced

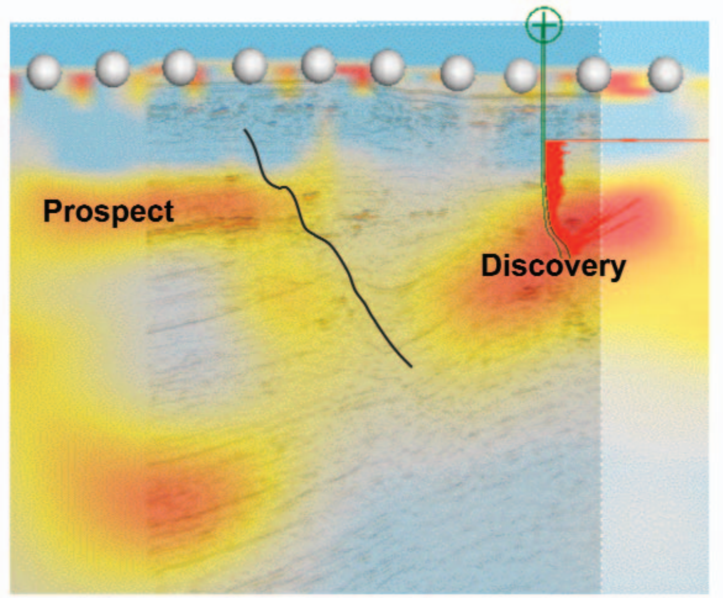

Figure 2. Depth section along 2-D line showing agreement with borehole resistivity log from the discovery well and confirmation of prospect.

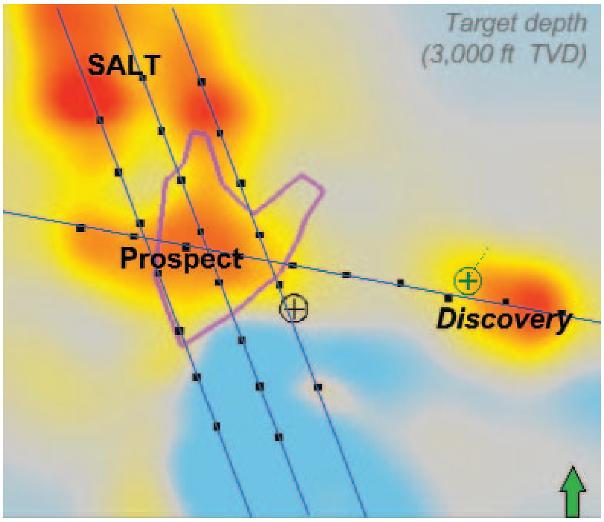

Figure 3. Map view of resistivity at target depth. Note the correct location of the discovery and confirmation of a resistor at the target. The resistor to the northwest is a large salt body. Note the dense receiver spacing (2,625 ft or 800 m) required to resolve multiple resistors in close proximity.

500-4,000m (~1,600-13,000 ft) apart. To achieve the penetration needed to "see" thin resistors several miles below the seabed, relatively low-base frequencies (0.1 - 0.2 Hz) must be used. When source transmissions are complete, an acoustic signal instructs the instruments to detach from their biodegradable seabed anchors and return to the surface with their precious cargo of EM data.

Advanced data processing and imaging methods can then be used to infer the distribution of subsurface resistivity that best explains the electric and magnetic fields measured at the seabed.

Expanding the 3-D EM application window

In the early days of EM, the method was limited to large, shallow targets in deep water with fairly simple clastic geologic environments. Over the past two to three years the second generation of EM data acquisition hardware and processing algorithms has dramatically increased the application window for EM.

- Increased source power has allowed the development of smart, broadband source signatures. A broader spectrum can improve the resolution of the method and enhance the ability to correctly resolve more complex stacked resistor situations (shallow hydrates or carbonates above the reservoir, resistive basements etc.).
- Increased receiver dynamic range has allowed the detection of small resistors in geologically "noisy" environments (i.e., close to salt).
- Larger vessels and more efficient operations have allowed the acquisition of cost-effective densely sampled 3-D grids.
- New processing methods have been developed to deal with complex shallow water reverberation and "air wave" issues.
- 3-D inversion has enabled more effective integration of EM resistivity-depth volumes with seismic data volumes and other subsurface data.

Changing the economics of mature basin exploration

Many small prospects remain undrilled for one simple reason — risk. It haunts every explorationist. A small marginally economic prospect may not get drilled if there is significant dry-hole risk. However, in a mature basin with readily available production and pipeline infrastructure, small prospects can be profitable if dry hole risk can be reduced to an acceptable level. This is where EM can create value in a mature basin.

One example of where this can be accomplished is in areas prone to low-saturation gas. Seismic amplitudes are very sensitive to low-saturation gas, and many beautiful amplitude anomalies remain undrilled for fear of fizz gas. On the other hand, resistivity changes very little at low gas-saturation levels, and EM is only likely to detect significant resistivity that is usually associated with commercial saturations.

In exploring for these small targets, it is important to keep costs low, but

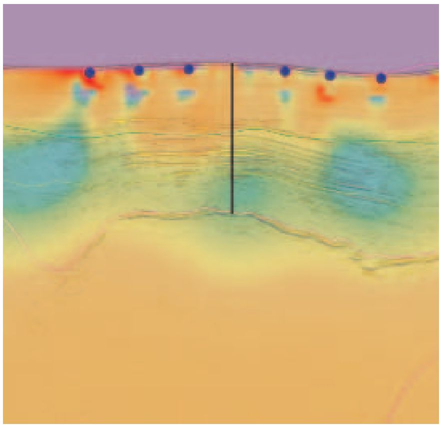

Figure 4. Preliminary inversion showing shallow resistive shale and deep resistive salt. Note the area to the west of the discovery well, where the shallow resistor appears to be thicker.

where cost-effective EM data can be acquired, it can tip the balance from non-economic to economic.

Case History #1

In this example, a shallow seismic amplitude anomaly was found in a fizz gas-prone area of the western GoM. A nearby discovery made the prospect interesting, but the case to drill was not sufficiently compelling. A small Clearplay TEST 3-D EM survey was designed to test the prospect, with a 2-D line connecting the target 3-D to the nearby discovery well that was believed to be analogous to the target prospect.

When the data was acquired, the 2-D calibration line clearly showed a resistor coincident with the previously drilled well. A resistor was also found at the target location, encouraging FOCUS Exploration to move forward with further prospect evaluation. A third deeper resistor was also found at a deeper level (Figure 2), and the seismic data is currently being evaluated to determine if this resistor is potentially hydrocarbon-related or the result of some other resistive material.

Case History #2

A well was drilled to test two seismic amplitude anomalies above a massive salt body (Figure 4). The shallower target was a modest discovery, but no pay was found at the deeper horizon. The well was abandoned and the lease relinquished.

In 2008, FOCUS Exploration approached EMGS to investigate the possibility of using EM to evaluate another small amplitude anomaly to the southeast of the discovery well that suggested the existence of additional pay downdip from the earlier discovery.

EMGS designed a dense, wide-azimuth Clearplay EVALUATE 3-D EM survey to test the downdip prospect and calibrate the technique at the discovery well. The first step in the analysis of the data was to perform an unconstrained 3-D inversion (Figure 4). This inversion clearly showed the expected deep salt layer and the resistive shallow shale layer. It is even possible to see a resistive anomaly around the discovery well.

An improved inversion product was then created by integrating structural knowledge of the depth of key resistive interfaces interpreted from 3-D seismic data (Figure 5). On this data, the resistor associated with three thin pay zones can clearly be observed as a discrete anomaly below the resistive shales. Detection of the reservoir at the discovery well gave FOCUS increased confidence in the prospect, and the EM response provided optimism for the hydrocarbons to extend significantly downdip from the proven pay. (Figure 6).

Conclusions

EM is still a new tool in the explorationist's toolbox. 3-D EM has only been available for two to three years. Explorationists are still testing the boundaries of what 3-D EM can do.

FOCUS Exploration's 2008 campaign in the Gulf of Mexico has demonstrated that 3-D EM can be used to reduce risk sufficiently to make small prospects economic. 3-D EM is particularly effective in reducing risk in areas where low-saturation gas can cause misleading seismic amplitude anomalies.

3-D EM has shown itself to be a surprisingly robust technique when working in a mature basin with complex geology. E&P

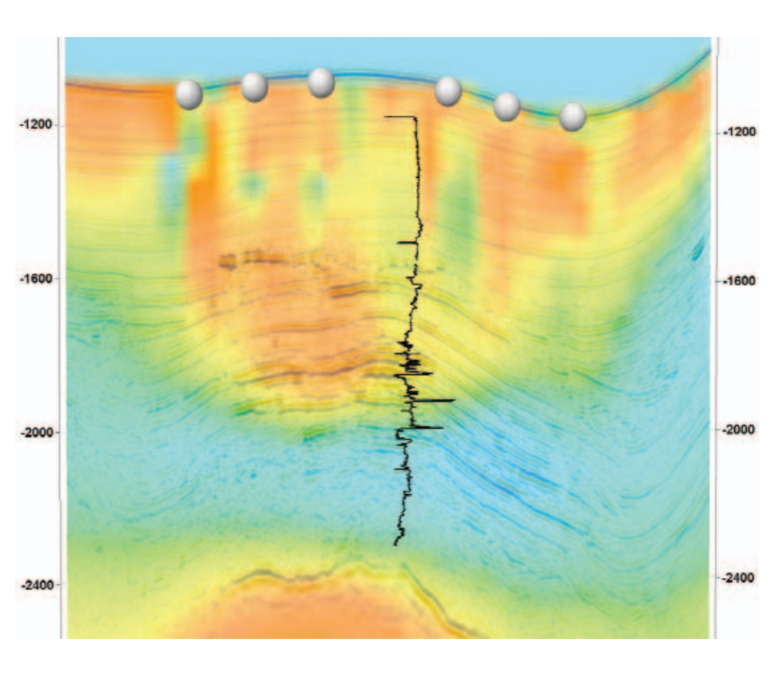

Figure 5. Detail of final inversion around the discovery well. Note the resistive anomaly that coincides with the package of three seismic amplitudes and the three resistive layers observed on the well log.

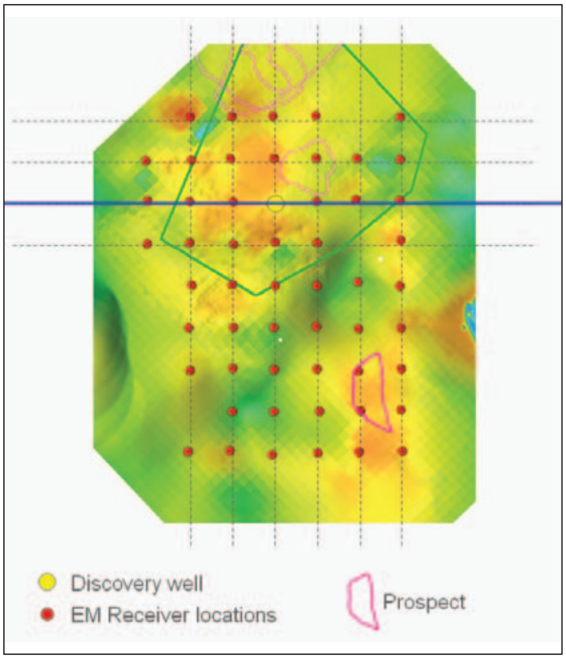

Figure 6. Map view of resistivity at prospect depth. Note the resistor at the discovery well to the north and at the new prospect to the southeast. (Blue line shows seismic line in Figures 4/5; yellow circle shows discovery well)